Design Guide: TIDA-020075

Automotive High-Voltage Battery Management System 2-Channel Pyro-Fuse Driver Board Reference Design

Description

The battery junction box of hybrid (FHEV, PHEV) and fully electric vehicles (BEV) integrates the core function of disconnecting the battery pack to protect the battery from excessive currents, permanent damage, or thermal runaway.

This reference design demonstrates how to build an automotive-grade, functional safety-compliant single- or dual-squib driver design.

The board size is 44mm × 130mm.

Resources

TIDA-020075	Design Folder
DRV3901-Q1	Product Folder

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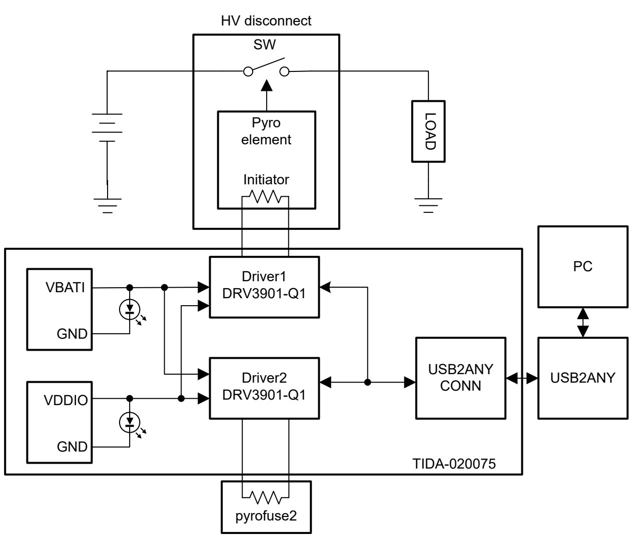
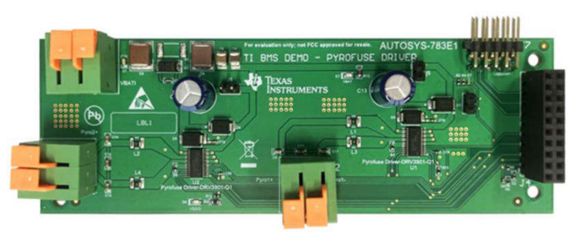
Features

- Fully integrated, single- or dual pyro-fuse driver design
- Reduced wiring harness effort in conjunction with TI's contactor drivers and pack monitors
- SPI for configuration, diagnostics, and deployment
- Level or heart beat, rapid hardware pin trigger function by pack-monitor overcurrent detection or collision sensors
- Optional energy reservoir capacitor integration
- ASIL-C safety goals to prevent unexpected battery pack disconnection and availability of disconnection function
- Reservoir storage diagnostics, output and short-to-supply diagnostics, built-in self-test, load (pyro) diagnostics

Applications

- HEV, EV battery-management system (BMS)
- Battery junction box
- High-voltage battery system





1 System Description

The battery junction box of hybrid (FHEV, PHEV) and full-electric vehicles (BEV) integrates the core function of disconnecting fuses to protect the battery pack from excessive currents, permanent damage, or thermal runaway. Key requirements are fast response time, reliable deployment when requested while avoiding false triggering, and high diagnostic coverage. Compared to blow or melting fuses, pyro-fuses excel in deployment time and flexibility in defining current profiles to trigger. Also pyro-fuses can be actively triggered not only in the event of excessive pack currents but in the event of a collision.

This reference design demonstrates how to build an automotive-grade, functional safety-compliant single- or dual-squib driver design.

This design showcases a single- or dual pyro-fuse driver for automotive applications in hybrid or full-electric vehicles running from a typical 12V supply rail. The TIDA-020075 features the DRV3901 device, a single-channel, highly integrated squib driver intended for automotive EV pyro-fuse applications. The device includes the power supplies, current sensing and regulation, and diagnostics and protection functions needed to drive a squib load. The design also incorporates several key functions unique to the device that are different from traditional squib drivers. These functions include a hardware pin trigger interface, an energy reservoir capacitor diagnostic, an addressable SPI, and optimized driver stage with integrated charge pump, and additional deployment current options.

To support a diagnostic for the system energy reservoir capacitor, the DRV3901-Q1 integrates a switch and monitor circuit to be able to bias and monitor the discharge voltage of the reservoir capacitor. This enables the device and the external MCU to detect a loss or failure of the reservoir capacitor or the approximate value in normal operation.

The power stage utilizes a protected high-side and low-side switch to provide robustness against unintended driving due to a variety of fault conditions. An integrated charge pump provides minimal drop-out voltage across the switches during deployment to enable operation down to low supply voltages. A wide variety of deployment options are available to optimize for different types of squib loads or for specific application requirements.

The pyro-fuse driver can be configured, safety-monitored, and employed through an addressable SPI bus. This reduces MCU resource requirements, and when sharing the SPI bus with TI's contactor drivers (DRV3946), the design reduces further wiring. Additionally, TI’s battery pack monitors (BQ79731) are equipped with an SPI hub to further reduce wiring effort and tunnel communication through the isolated vertical interface (VIF).

The SPI incorporates multiple robustness functions including a CRC, address readback capability, and various bus fault detection mechanisms.

As an alternative trigger method, the hardware pin trigger (TRGx) interface allows for a deployment command to be issued directly in hardware to the DRV3901-Q1. This allows the flexibility to either trigger the deployment with MCU hardware pins, directly with the overcurrent function of the pack monitor (BQ79731), or through other external hardware such as the airbag collision detection. The hardware trigger pins support a 2-pin interface with both threshold or PWM-based options to provide robustness against miss deployment while still providing flexibility to support a variety of interface options.

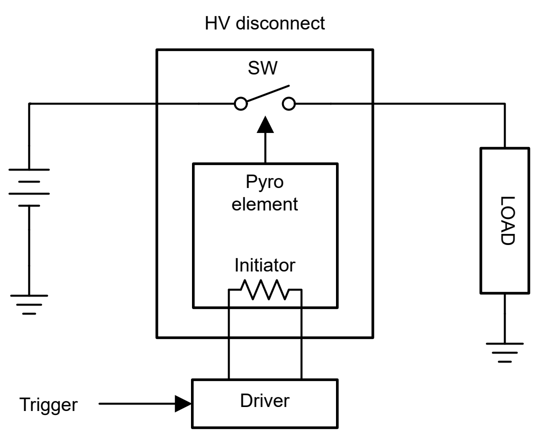


Figure 1-1. Typical Pyro-Fuse Driver System

1.1 Key System Specifications

Table 1-1. Key System Specifications

ITEM	DESCRIPTION	TYP	UNIT
VBATI	Power supply voltage	5 to 28	V
VDDIO	Logic supply voltage	4.5 to 5.5	V
TA	Operating ambient temperature	–40 to 125	°C

2 System Overview

2.1 Block Diagram

Figure 2-1 shows the system-level functional block diagram with the DRV3901 as pyro-fuse driver. This function is repeated twice in case a dual pyro-fuse design is implemented.

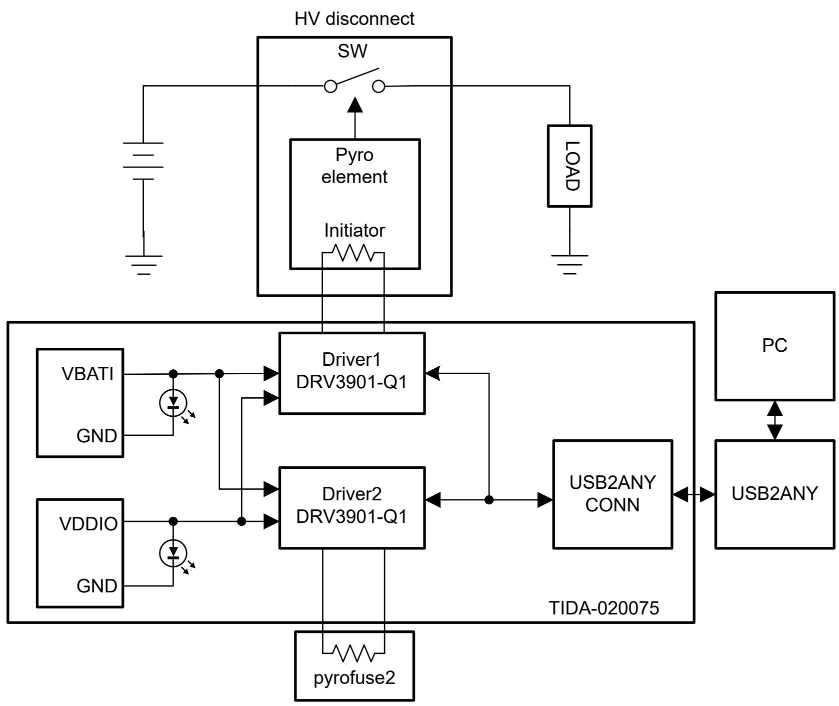


Figure 2-1. TIDA-020075 System-Level Functional Block Diagram

Figure 2-2 is the schematic for the TIDA-020075 design.

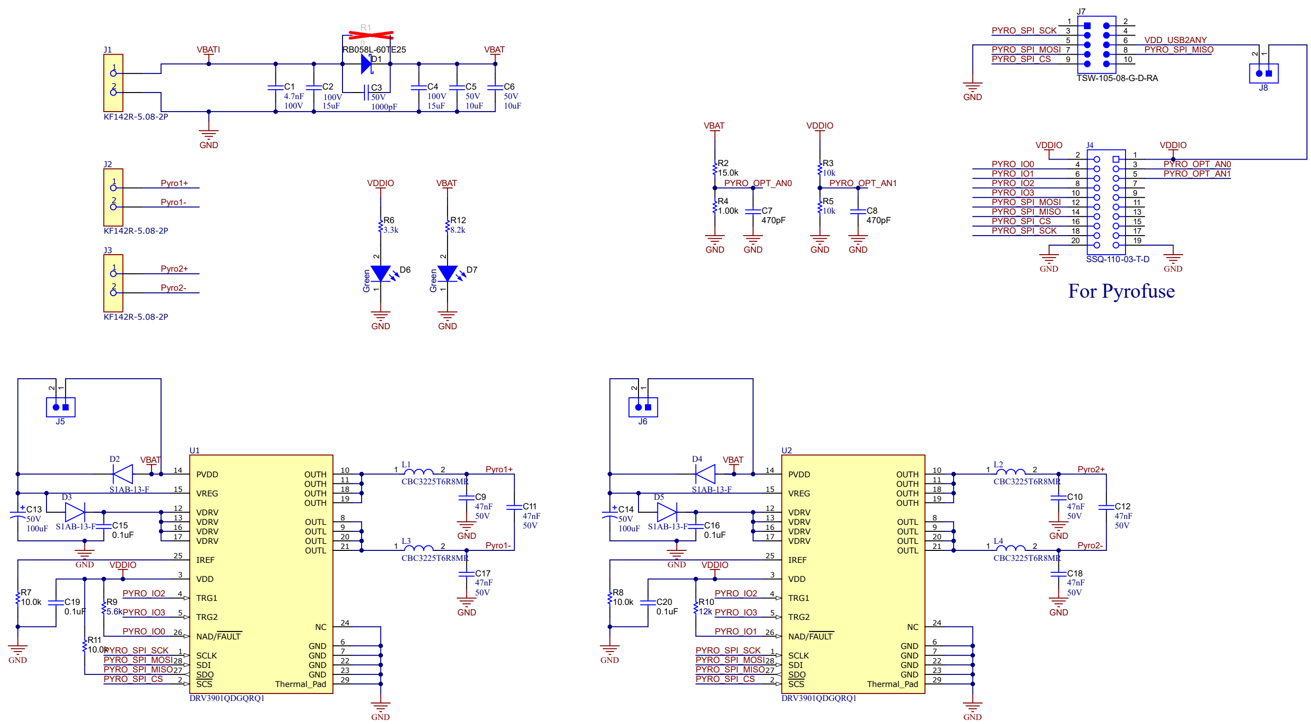


Figure 2-2. TIDA-020075 Design Schematic

2.2 Design Considerations

This reference design features an automotive disconnect unit. The design is part of a whole automotive BMS evaluation platform to equip interested customers with a fast method to start evaluation towards a later industrialization.

2.3 Highlighted Products

2.3.1 DRV3901-Q1

The DRV3901-Q1 is a highly integrated squib driver intended for automotive EV pyro-fuse applications. The device includes the power supplies, current sensing and regulation, and diagnostics and protection functions needed to drive a squib load. The DRV3901-Q1 incorporates several key functions unique to the device that are different from traditional squib drivers. These functions include a hardware pin trigger interface, an energy reservoir capacitor diagnostic, an addressable SPI, and optimized driver stage with integrated charge pump and additional deployment current options.

Key features of the DRV3901-Q1 include:

- AEC-Q100 qualified for automotive applications
  - Temperature grade 1: –40°C to +125°C, T_A
- Functional Safety-Compliant
  - Developed for functional safety applications
  - Documentation to aid ISO26262 system design up to ASIL C
- Highly integrated squib driver design targeted at automotive EV pyro-fuse application
  - Integration of power supplies, current regulation, diagnostics, and safety functions
  - SPI or hardware pin-based triggering for flexible interface options and rapid firing reaction
  - Diagnostic functions for system energy reservoir capacitor and squib health monitoring
  - Built-in-self-test and diagnostic functions for power supplies, interfaces, drivers, and monitors
  - Architecture for reliable operation with redundant power supplies, low-side and high-driver drivers, and secondary monitoring logic
- Up to 28V (40V absolute maximum) operating voltage
- Compact HVSSOP-28 (DGQ) leaded package
- Two-wire load interface with protected, current controlled high-side and protected secondary low-side switches
- Integrated charge pump for minimal MOSFET drop out voltage
- 4-wire, addressable, 24-bit SPI with CRC protection
  - Allows multiple device to operate on the same SPI
  - Allows for broadcast commands to multiple devices.
- Configurable deployment currents (1.2A, 2ms; 1.75A, 0.5ms; up to 3.4A, 0.5ms)
- Configurable deployment interface options
  - 2-pin HW trigger with PWM or level signaling
  - Protected SPI command with CRC
- Comprehensive off-state diagnostics
  - Device built-in-self-test
  - Driver output and switch test
  - Interface test
  - Energy reservoir capacitor test
  - Squib resistance test
- Configurable fault indicator (nFAULT)

3 System Design Theory

The pyro-fuse driver system design is based on original equipment manufacturer (OEM) requirements. This reference design can handle most designer requirements with the given topology and diagnosis requirements.

- Differences compared to the conventional fuse:
  - Much faster disconnect process minimizes arc formation.
  - A special driver is required. Firing high-voltage disconnect requires specific current and timing setting.
  - Active triggering enables controlled and consistent disconnect.

4 Hardware, Software, Testing Requirements, and Test Results

4.1 Hardware Requirements

The TIDA-020075 is categorized into two sections to explain the design in terms of the application:

- Driver
- Power and connectors

TRG1 and TRG2 is the DRV3901-Q1 hardware trigger. The device can also be triggered with SPI. J5 and J6 are not connected as default and are not needed for the final customer design. The device needs to be connected only when the D2 and D4 connections were broken. A local energy reservoir capacitor on VREG is required to supply the driver in loss of PVDD power supply fault condition.

Figure 4-3 shows where different pin headers, LEDs, and connectors are located on the PCB.

There are 2 LEDs to indicate the state of the power. D6 lights on if VOOIO is power on, D7 lights on if VBATI is power on.

For connectors, J1 is the input of VBATI, J2 and J3 are the output of pyro-fuse driver. J7 is the USB2ANY port and can be used to configure and trigger DRV3901-Q1. J4 is the port connect with another demonstration board – the bus controller unit (BCU) board – the controller board of the BMS system.

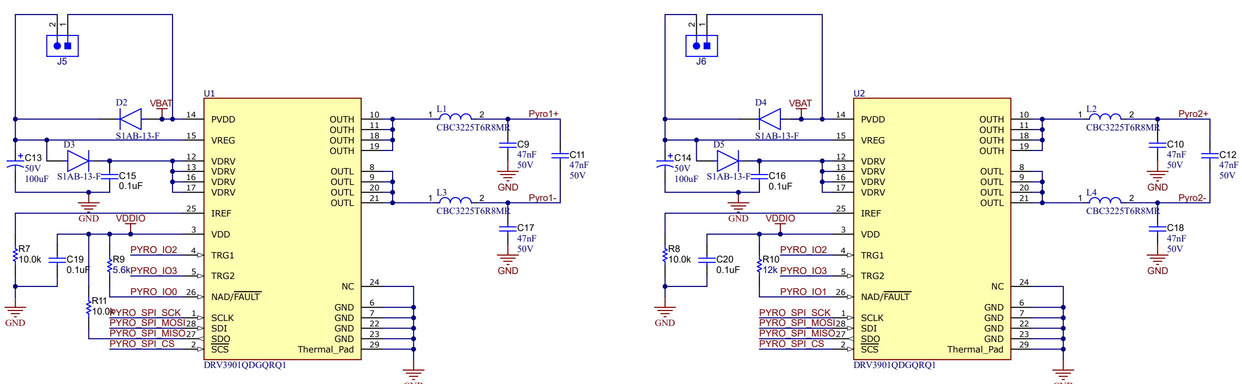


Figure 4-1. TIDA-020075 Schematic: Driver

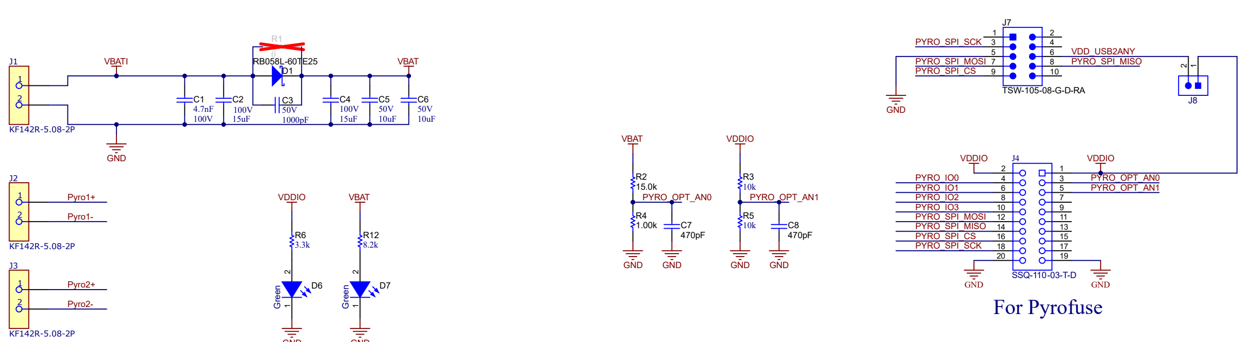


Figure 4-2. TIDA-020075 Schematic: Power and Connectors

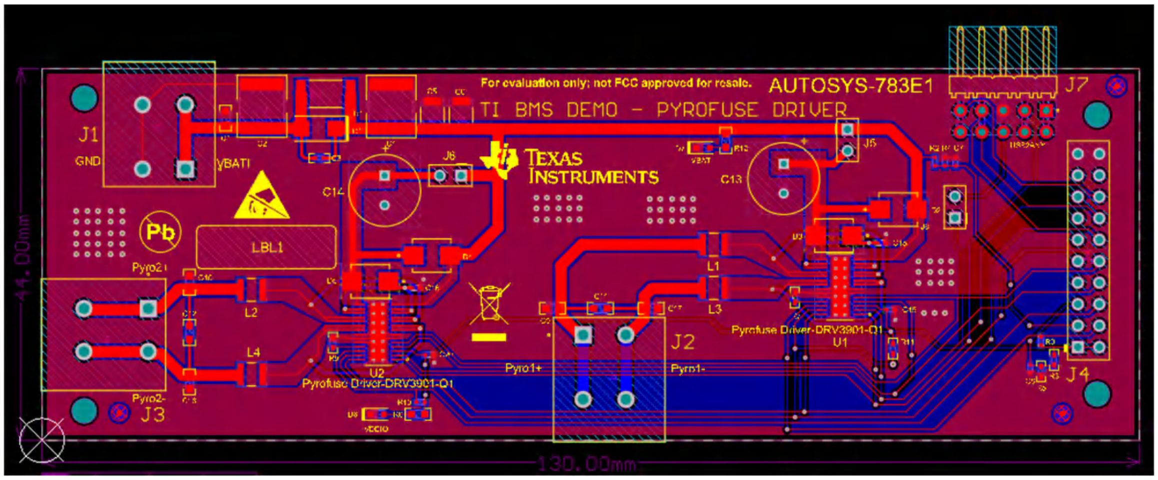


Figure 4-3. TIDA-020075 PCB Layout Top

4.2 Software Requirements

The reference design needs a USB2ANY explorer installed in the PC. This USB2ANY explorer can be used to configure the trigger of the pyro-fuse.

4.3 Test Setup

Section 4.3.1 and Section 4.3.2 provide details of the test setup.

4.3.1 Hardware Setup

Use the following steps and reference Figure 4-4 to setup the hardware:

1. Connect 12V to the power input(J1), connect 5V with J4, connect two pyro-fuses or 2Ω resistors to J2 and J3.
2. Connect a USB2ANY to J7 and export to a computer.
3. Use an oscilloscope to monitor the output of J2 and J3.

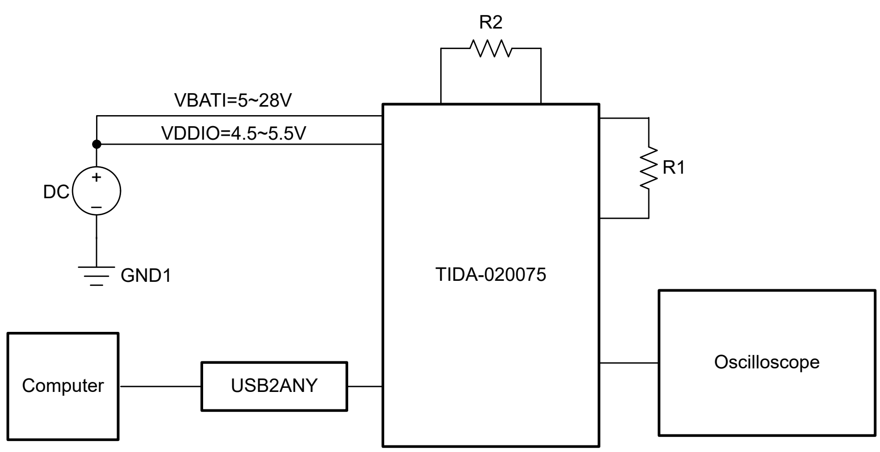


Figure 4-4. TIDA-020075 Hardware Test Setup

4.3.2 USB2ANY Explorer Setup

Before connecting the USB2ANY, be sure the device is connected correctly, Figure 4-5 shows the details of the USB2ANY port.

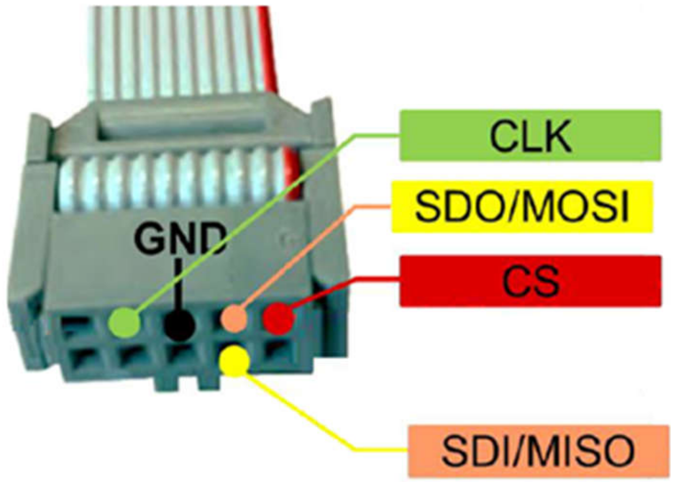


Figure 4-5. TIDA-020075 USB2ANY Test Setup

After installing the *USB2ANY Explorer* software from the product page, connect the USB2ANY device to the computer and open USB2ANY Explorer. The software automatically detects the device and makes the connection. If the connection fails, press the *Open Device* button in the top left. If the software requests an update to the device firmware, update the firmware immediately following the on-screen instructions.

Follow these steps to set up SPI communication for use with the DRV3901:

1. Click *Select Interfaces*, select SPI, and close that menu.
2. Click the *SPI* button beside debug. If the software glitches and does not show the SPI button, click the area between *Activity logging* as Figure 4-6 shows.

Figure 4-6. TIDA-020075 USB2ANY Explorer Test Setup1

3. Make the following settings:
   - Clock Polarity: Inactive Low
   - Clock Phase: Trailing Edge
   - CS Polarity: Active Low
   - Bit Direction: MSB First
   - Length: 8 Bits
   - Bit Rate: 1000KHz
   - CS Type: Per Packet
   - Type three bytes in the *Write data* box and the box on the right auto-sets to 3 bytes.

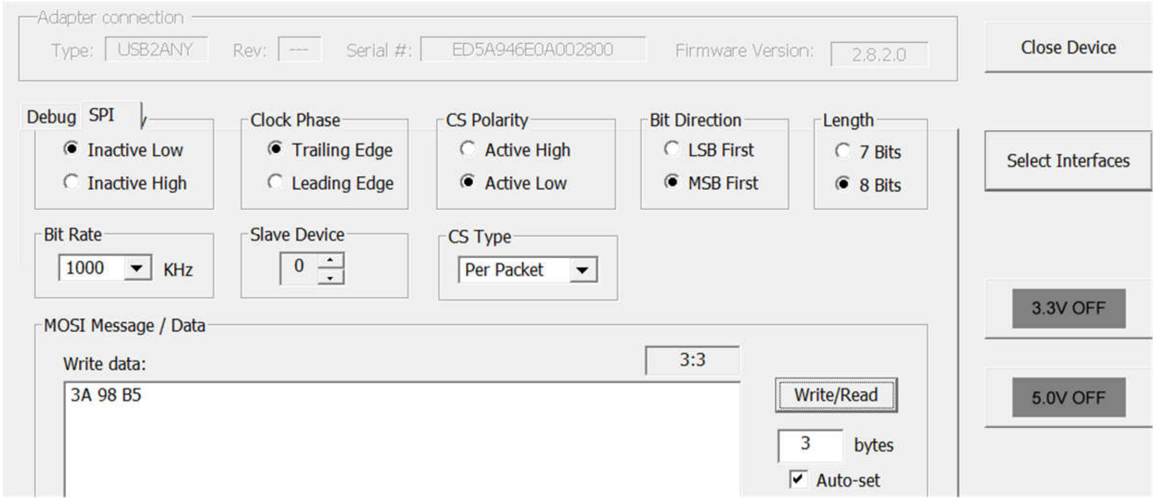


Figure 4-7. TIDA-020075 USB2ANY Explorer Test Setup2

At this point, the USB2ANY device is configured to communicate with a DRV3901 chip.

4.4 Test Results

When the test setup is ready, write the deploy command, 3C 84 D8, the pyro-fuse is triggered (only when using the real pyro-fuse), and a trigger waveform can be obtained on the oscilloscope. Figure 4-8 illustrates the test result. The chip is supposed to deploy for approximately 2ms with the current limited to 1.2A, which is as expected.

Figure 4-8. TIDA-020075 Test Result

5 Design and Documentation Support

5.1 Design Files

5.1.1 Schematics

To download the schematics, see the design files at TIDA-020075.

5.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-020075.

5.1.3 PCB Layout Recommendations

The PCB layout of a pyro-fuse driver module must be done based on the arrangement and floor plan of a complete PCB.

1. Leave component R1 unpopulated.
   - A resistor can be populated here when the anti-reverse diode D1 is not needed.
2. Use 0Ω resistor instead for L1, L2, L3, and L4.

5.1.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-020075

5.2 Tools and Software

Tools

USB2ANY	USB2ANY interface adapter

Software

SLVC695	USB2ANY Explorer Software

5.3 Documentation Support

1. Texas Instruments, *DRV3901-Q1 Single Channel Squib Driver For Automotive EV Pyro-Fuse Data Sheet*

5.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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6 About the Author

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